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FINAL REGULATORY EVALUATION, REGULATORY FLEXIBILITY ANALYSIS, INTERNATIONAL TRADE IMPACT ASSESSMENT AND UNFUNDED MANDATES ANALYSIS

Airworthiness Standards; Bird Ingestion Standards

Final Rule
(14 CFR Part 33)

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Executive Summary

This regulatory evaluation uses the same methodology as the earlier NPRM analysis to estimate the benefits and costs of a rule to revise Title 14 part 33 of the Code of Federal Regulations (CFR) by introducing additional bird ingestion tolerance requirements for aircraft turbine engines. In the period following the NPRM publication, there were no comments regarding the regulatory evaluation. The rule consolidates existing and new bird ingestion standards in a new section §33.76. Concomitantly, bird ingestion standards now specified in §33.77(a) and (b) are removed. In addition, 14 CFR parts 23 and 25 will be amended consistent with the changes to part 33.

Incremental costs. Costs of the rule include one-time certification costs and recurrent fuel costs due to reduced fuel efficiency. The FAA estimates that the provisions of the rule will add \$250,000 to \$500,000 to certification costs depending on engine inlet area. The additional analysis required to verify the effects of a large bird impact on the front of the engine could necessitate a component test costing \$250,000. Also, the rule will require additional analysis or testing on the full fan assembly for engines with inlet areas greater than 2,092 square inches. Such testing is estimated to cost approximately \$250,000.

In addition, the revised medium bird test weights could necessitate strengthening fan components, thereby affecting fan performance. FAA estimates that reduced fan efficiency would result in a 0.2% increase in fuel consumption. On average, this would increase annual fuel costs by \$4,770 per airplane.

Benefits. The rule is a result of an airplane accident, followed by a NTSB recommendation and a number of studies conducted by industry and the FAA. Since the NPRM, at least three new incidents have occurred involving bird ingestion. Benefits associated with the rule include: 1) averted fatalities and injuries, 2) averted property damage (primarily hull losses), and 3) reduced maintenance and repair costs. Based on historical accident data and information obtained from industry, FAA estimates that the expected annual per-airplane benefit from averted airplane damage or loss is approximately $657. The expected annual per-airplane benefit from averted fatalities and injuries is $654 and $75, respectively.

The estimated value of maintenance/repair savings associated with the rule is based on an analysis of the relationship between bird ingestion weight and the probability of damage. FAA estimates that, on average, the rule will result in operator maintenance/repair savings of approximately $4,654 per airplane per year.

Comparison of benefits and costs. Estimated discounted benefits of the rule, at $4.333 million, exceed the estimated discounted costs of $3.906 million.

Regulatory Flexibility Determination. The FAA has determined that it will not have a significant economic impact on a substantial number of small entities.

International Trade Impact Assessment. The FAA has assessed the potential effect of this rule and has determined that it will impose the same costs on domestic and international entities and thus has a neutral trade impact.

Unfunded Mandates Analysis. This rule does not contain a Federal intergovernmental or private sector mandate that exceeds $100 million in any one year.

Airworthiness Standards: Bird Ingestion Standards

I. Introduction

This regulatory evaluation estimates the benefits and costs of a rule to revise Title 14 part 33 of the Code of Federal Regulations (CFR) by introducing additional bird ingestion tolerance requirements for aircraft turbine engines. The rule consolidates existing and new bird ingestion standards in new section §33.76. Concomitantly, bird ingestion standards previously specified in §33.77(a) and (b) will be removed. In addition, 14 CFR parts 23 and 25 will be amended consistent with the changes to part 33. The rule's major provisions are summarized below.

A. Revised large bird ingestion standards

Current regulations preclude fire, burst, the generation of unsafe loads, or the loss of shutdown capability following the ingestion of a single 4 pound bird. The rule will amend this requirement in several ways.

First, the rule [new §33.76(a)(3)] will require testing or analysis to verify that a large bird strike against associated engine components (such as the nose cone/spinner, inlet guide vane assemblies, and engine protection devices) will not affect the engine to the extent that it cannot comply with the ingestion test acceptance criteria specified in new §33.76(b)(3) and §33.76(c)(6).

Second, the rule establishes a schedule of large bird test weights which will vary - as a function of engine inlet area - from approximately 4 pounds (for engines with an inlet area of less than 2,092 square inches) to approximately 8 pounds (for engines with an inlet area of 6,045 square inches or more) [Table 1 of new §33.76(b)]. These revised standards will more accurately represent the bird threat observed in service.

Finally, new §33.76(b)(4) will allow manufacturers to forego the large bird test if it can be shown that the containment standards of §33.94(a) (blade containment and rotor unbalance tests) constitute a more severe requirement.

B. Revised medium bird ingestion standards

The rule also modifies the standards for medium bird ingestion. The current regulations require a test simulating a flock encounter with 1.5 pound birds, where bird quantity is a function of the engine inlet area (up to a maximum of eight birds). Under the new §33.76(c)(2), both bird weight and quantity will be functions of the engine inlet area.

In addition to these weight and quantity modifications, the rule will revise medium bird ingestion test procedures. Bird speed - previously specified as the initial climb speed of a typical aircraft - will, under this rule, be determined by analysis or testing as part of the identification of critical ingestion parameters (e.g. bird speed, target locations, first stage rotor speed) [new §33.76(c)(1)]. Also, the medium and small bird tests will require an engine to be run for 20 minutes following ingestion (previous regulations called for a 5 minute run-on) [new §33.76(c)(7)].

C. Revised small bird ingestion standards

While small bird weights and quantities will be unaffected by this rule, test procedures will be revised in a fashion similar to the medium bird tests: 1) bird speed will be determined as part of the critical ingestion parameter analyses [new §33.76(c)(1)], and 2) the ingestion test schedule will include 20 minutes of post-ingestion engine operation [new §33.76(c)(7)].

II. Background

Depending on their mass and quantity, ingested birds can impede turbine engine operation to varying degrees. Damage can include: 1) bent fan blades (which reduce fan efficiency), 2) transverse blade fractures (in which a fan blade is broken chordwise, perhaps causing secondary damage to the engine), or 3) core damage (bent or broken compressor blades or vanes, perhaps involving blocked or disrupted airflow in the low, intermediate, or high pressure compressors).

Currently, aircraft turbine engines must be capable of ingesting a 4-pound bird without potentially hazardous consequences such as fire, ejection of engine fragments through the case, or the loss of shutdown capability. This requirement is referred to as the "safe shutdown" criterion. The medium and small bird tests - which address situations where a multiple engine event is more likely - are designed to verify that an engine can continue to operate with no more than a 25 percent power loss after bird ingestion.

The origins of existing turbine engine bird ingestion standards can be traced to the early 1960's when the FAA issued a series of advisory circulars that outlined foreign object ingestion requirements. In June of 1969, industry and government officials met at an agency-sponsored conference to discuss ways of improving aircraft engine certification requirements. Some of the ideas advanced at that conference were incorporated into a proposed rule published in May 1971 (36 FR 8383) and published in final form in October 1974 (39 FR 35467). The new regulations defined certification requirements for foreign object ingestion (§33.77) and, in particular, established the bird ingestion test trichotomy that exists today: 1) up to 16 3-ounce birds ingested in rapid sequence to simulate a flock encounter, 2) up to eight 1.5 pound birds ingested in rapid sequence to simulate a flock encounter, and 3) one 4-pound bird aimed at a critical area. A subsequent rulemaking, published on February 23, 1984 (49 FR 6852) clarified engine test and design requirements and upgraded certain standards (including bird ingestion test procedures) to account for the increasing complexity of aircraft engines.

This rulemaking arose from a number of studies conducted by the FAA, the Aerospace Industries Association (AIA) and the Association Europeenne Des Constructeurs De Materiel Aerospatial (AECMA). These studies showed that despite the then-existing design requirements, bird ingestions were still a persistent hazard. For example, the ingestion rate for large high bypass ratio turbofan engines is approximately 2.04×10^{-4} ingestions per aircraft operation. Half of these cases result in damage to the engine and one-eighth of these events require crew action (e.g. aborted takeoffs, diversions). Approximately 2.4 percent of the cases result in an in-flight shutdown of the engine.[1]

III. Economic Analysis

1 Banilower, Howard, *Bird Ingestion into Large Turbofan Engines*, U.S. Department of Transportation, Federal Aviation Administration, DOT/FAA/CT-93-14, February, 1995, p. xi.

This final regulatory evaluation measures costs in 1996 dollars, as did the preliminary regulatory evaluation. On this basis, the discounted benefits of the rule, at $4.333 million, exceed the discounted costs of $3.906 million. These values have changed very little since 1996. The FAA has not changed the estimated value of a fatality since 1996. Certification costs were originally estimates of the upper bound of the potential range. The cost of fuel to air carriers used in this analysis is 56.4 cents per gallon. This was an accurate estimate until recently, when a steep increase in fuel prices occurred in the U.S. in the first half of the year 2000. Currently, these prices are fluctuating on almost a daily basis, but are forecasted to come down over the next year. Accordingly, this analysis has not been recalculated to reflect the current price spike because unstable present prices are expected to decrease in the near future.

A. Incremental costs

1. Incremental costs associated with the large bird amendments

Under existing regulations, engine manufacturers must show that the ingestion of a large bird will not cause a hazardous condition [as described in §33.77(a)]. In practice, this requirement can be met by demonstrating that §33.94 (blade containment and rotor imbalance) represents a more severe test. Revised §33.76(b)(4) simply codifies this policy and consequently, it will not affect certification costs.

Revised §33.76(b)(1) will increase large bird weight from 4 pounds to as much as 8 pounds depending on inlet size. According to industry representatives, however, this provision will have little effect on the cost of future engine certifications. This follows for several reasons. First, there is no change in specified bird weights for engines with inlet sizes less than 2,092 square inches. Second, engine manufacturers are already responding to air carrier (in particular, operators of large twin-engine transport aircraft) demand for engines with greater bird ingestion tolerance. Finally, for recent designs, the existing blade-out requirement (§33.94) has proven to be a more severe test than the new large bird requirement.[2]

The rule will also require additional analysis or testing to verify the effects of a large bird impact on the front of the engine. This demonstration could require a component test costing $250,000. Industry representatives have stated, however, that future engine designs meeting the large bird requirements of these amendments will be able to meet the engine-front impact requirement without incurring additional manufacturing costs or weight or performance penalties. There are expected to be small performance penalties associated with meeting the medium/small bird amendments, as discussed in the next section.

2. Incremental costs associated with the medium/small bird amendments

Several amendments, from this rule, to the medium and small bird ingestion standards will result in little or no incremental cost:

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[2] According to one expert, this result is likely to persist given modern, wide-chord, fan blade designs. Although fan blades for large turbine engines can weigh as much as 40 pounds, it is theoretically possible that a large bird impact could affect a greater number of adjacent blades (thereby producing more severe rotor imbalance) than a single blade-out. Thus, component testing or analysis is required to verify which is the more severe test. Also, the relative severity of the two tests varies with engine size.

1) §33.76(a)(3) will require evaluation of a medium bird strike against the front of the engine. Although such an evaluation is not explicitly contained in 14 CFR Part 33, existing FAA policy requires the consideration of an engine-front impact as part of medium and small bird ingestion analyses.

2) §33.76(a)(1) will require manufacturers to account for engine operation at sea level take-off conditions on the hottest day that a minimum engine can achieve maximum rated take-off thrust or power. Industry representatives state that this provision will generate little incremental costs.

3) §33.76(c)(7) will require the test engine to be run for 20 minutes (at various specified power levels) following bird ingestion. The existing regulation calls for 5-minutes of engine operation. FAA and industry representatives judge the incremental costs associated with this provision to be negligible.

4) §33.76(c)(9) will waive compliance with the test provisions of §33.76(c)(1)-(8) for engines limited to multi-engine rotorcraft installations. This change is expected to reduce manufacturing and operating costs.

a. Engines with inlet areas greater than 2,092 square inches

The rule will raise medium bird ingestion standards for engines with inlet areas greater than 2,092 square inches. It will mandate additional testing or analysis on the full fan assembly and will also increase the weight of the largest medium test bird (Table 2 of the Amendment). Based on discussions with industry, the FAA estimates that the required full fan assembly analysis or rig test will cost approximately $250,000.

Incremental certification and manufacturing costs associated with the medium bird weight revision are expected to be negligible. However, the revised test weight will necessitate strengthening fan components, thereby affecting fan performance. It has been estimated, by a manufacturer, that reduced fan efficiency will conservatively result in a 0.2% increase in fuel consumption. The average annual per-airplane effect on fuel consumption is computed in Table 1. With regard to the sensitivity of these results, two items are noted: First, the estimate of the reduced fan efficiency is on the conservative side; and second, the price of jet fuel in 1999 was similar to that in 1996.

Table 1. **Incremental Fuel Consumption Cost Under the Rule**
(Incremental fuel cost per aircraft per year)

AC Category	Gal/hr per AC (1)	0.2% Effect (2)	Annual Fleet Hours (3)	Annual Fleet Cost (4)	Active AC (5)	Cost/AC /Year (6)
4-eng wide-body	3,617.0	7.2340	554,706	$2,263,187	186	$12,168
4-eng narrow-body	2,104.0	4.2080	344,187	816,863	234	3,491
3-eng wide-body	3,003.5	6.0070	982,704	3,329,350	330	10,089
3-eng narrow-body	1,817.0	3.6340	1,612,445	3,304,829	906	3,648
2-eng wide-body	1,716.5	3.4330	997,548	1,931,464	274	7,049
2-eng narrow-body	1,282.0	2.5640	7,237,651	10,466,338	2,706	3,868
Weighted annual incremental fuel cost per aircraft						$4,770

(1) Total fuel burn. Washington Consulting Group, *Impact of Weight Changes on Aircraft Fuel Consumption*, January 12, 1994, PP 4-9.
(2) Incremental fuel consumption [column (1) times 0.002].
(3) Federal Aviation Administration, *FAA Statistical Handbook of Aviation, Calendar Year 1994*, Table 5.3. (Note: these data have not been published, but are available on the FAA website.)
(4) Column (2) times column (3) times $0.564 [the air carrier price of jet fuel in 1996 dollars]. Federal Aviation Administration, *FAA Aviation*

Forecasts, Fiscal Years 1996-2007, Table 6.--Baseline Air Carrier Forecast Assumptions, p IX-8.

(5) *FAA Statistical Handbook of Aviation, Calendar Year 1994*, Table 5.2.

(6) Average incremental fuel cost per aircraft per year is computed by dividing total incremental annual cost [the sum of column (4)] by the total number of in-service aircraft [the sum of column (5)].

b. Engines with inlet areas less than 2,092 square inches

The rule will have a negligible effect on operating and production costs for engines with inlet areas less than 2,092 square inches: new medium bird weights are essentially unchanged for engines with inlet areas between 620 and 2,092 square inches, and are lower for engines with inlet areas less than 620 square inches. Table 2 summarizes the cost effects of the rule.

Table 2. **Summary of Incremental Costs, by Rule Provision and Engine Inlet Size**

Rule Provision	Large Engines (>~2,100 in^2)	Small Engines (<~2,100 in^2)
Large Bird Req.'s		
Eng.-Front Impact §33.76(a)(3)	Component test: $250,000	Component test: $250,000
Revised bird wt. §33.76(b)	Negligible cost effect	Negligible cost effect
§33.76(b)(4)	Existing practice	Existing practice
Med Bird Req.'s		
Eng.-Front Impact	Existing practice	Existing practice.
Revised bird wt. and speeds	Reduced fan efficiency	Negligible cost effect
Full-fan assembly §33.76(c)(3)	Component test and/or analysis: $250,000	Not applicable
Hot day condition	Negligible cost effect	Negligible cost effect
20 min. run-on §33.76(c)(8)-(9)	Negligible cost effect	Negligible cost effect

B. Incremental benefits

1. Benefits of reduced fatalities and injuries

The annual benefits associated with the reduced risk of casualties, B_c, can be computed as:

$$B_c = (D \times (P_c - P_n)) \times [((P_f \times N) \times V_f) + (((P_i \times N) \times V_i)]$$

Where,

D = The number of departures per year (approximately 1,500)

P_c = The rate of a bird ingestion-related accidents per departure under previous regulations

P_n = The rate of a bird ingestion-related accident per departure under the new rule

N = The average number of occupants per airplane departure

P_f = The conditional probability of being killed given an accident

P_i = The conditional probability of being injured given an accident

V_f = The value of a fatality averted

V_i = The value of an injury averted

Accident probability estimates are based on historical information obtained from several sources including: 1) The FAA Accident/Incident Database System, 2) accident records from the National Transportation Safety Board (NTSB), 3) FAA Technical Center analyses of bird ingestion events, and 4) information submitted by engine manufacturers.

As noted above, bird ingestion events are not uncommon, occurring at a rate of approximately 204 ingestions per million aircraft operations. A very small fraction of this number results in a major failure condition. The FAA - using the sources cited above - documented 13 cases world-wide involving a large commercial jet transport in which ingested birds caused either a crash (five cases) or loss of power exceeding 25% to more than one engine (eight cases) - for the 20-year period 1975-1994.[3] During this period, air carriers logged 241.5 million departures.[4] Thus, a major failure condition occurs at a rate of approximately 5.4 events per 10^8 departures, and the accident rate is approximately 2.1 per 10^8.

Table 3. **Estimated Reduction in Accident Rate**
(For a notional transport category airplane)

(1) Departures 1975-1994 (millions)	241.5
(2) Hull losses	5
(3) Est. loss/million departures w/o rule	0.0207
(4) Est. loss/million departures w/ rule	0.0021
(5) Est. risk reduction/million departures	0.0186
(6) Air Carrier departures/yr./AC (mil.)	0.0015

Line (1): Historical worldwide departures (see footnote 4).
Line (3): Ratio of lines (2) and (1).
Line (4): Estimate of risk reduction provided by ARAC.
Line (5): Difference between lines (3) and (4).
Line (6): Ratio of 1) 1992 departures for large certificated air carriers (source: Department of Transportation, Research and Special Programs Administration, *Air Carrier Traffic Statistics Monthly*), and 2) 1992 number of active aircraft (source: FAA, *Census of U.S. Civil Aircraft*).

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3 The accidents involved a DC-10 in 1975, a B737 in 1978, an A300B in 1986, a B737 in 1988, and a B707 in 1990. These totals do not include three incidents involving U. S. Air Force military variants of commercial transports. See Appendix I.

4 World-wide departures are from the International Civil Aviation Organization (ICAO) *Civil Aviation Statistics of the World* (various issues). Estimates of the rule's potential benefits are based on world-wide service records for a number of reasons: 1) Manufacturers were not able to provide engine operating data broken into domestic and foreign components. 2) While bird control procedures differ between countries, many researchers point out that underreporting in the U.S. makes it difficult to draw conclusions regarding the differences between domestic and foreign ingestion rates. Banilower, *op. cit.*, for example, concludes that "it is unlikely that domestic engine events were underreported relative to foreign by less than 20 percent. The best estimate is that underreporting is over 100 percent, but may be 200 percent or higher."

According to an industry expert, the rule is expected to reduce the accident rate by one order of magnitude or 90%. Therefore, the reduction in risk (the difference between the accident rate under the previous regulations and under this rule) is approximately 1.9 per 10^8 (see Table 3).

Accidents involving bird ingestion have continued to occur over more recent years. These include an accident (January 1998) in which a Boeing-727, while climbing through 6,000 feet following takeoff from Houston Intercontinental Airport, struck a flock a snow geese with 3-5 birds ingested in one engine. The engine lost all its power and was destroyed. An emergency was declared and the flight returned to Houston with major damage to the aircraft. In another case (August 1998), a Jetstream-31 hit a mixed flock of birds (22 doves and killdeer) while landing (in Altoona-Blair County Airport - PA). After ingesting birds, one engine was shut down and was later removed for overhaul. In another more recent case (March 1999), a DC-9 cargo plane while landing in Kansas City International Airport stuck several snow geese. Geese were ingested into both engines, and one engine was destroyed while the other lost 50% of its power. The pilot was able to land the aircraft safely.[5]

In addition, other information indicates an increasing threat of bird ingestion in recent years. Data show that over 1990-1999, there was an increase in damage to airplane engines as a result of bird strike. These data show the effect of bird strike in the airplane engine as "struck" and "damaged"; and those events under the classification "damaged" would tend to be the result of bird ingestion. These cases are shown to have increased from 158 in 1990 to 246 in 1999. This development has also been accompanied by an increase in the

[5] E. C. Cleary (FAA) and R. A. Dolbeer (USDA - Wildlife Services), "Wildlife Hazard Management at Airports", December 1999.

number of cases when airplane engines were shut down (consistent with an outcome of bird ingestion): from 7 in 1990 to 19 in 1999.[6]

Finally, a recent review of data on bird strikes on aircraft and engine bird ingestion (composed of data contained in the FAA database, combined with data from several U.S. engine manufacturers), has shown that the increasing population of geese in North America has resulted in a rise in goose strikes to civil aircraft, and in an increased number of engine ingestion events. Based on this information, the FAA believes that there is an increased probability of multiple engine ingestion of large birds with significant loss of total aircraft thrust.

Projecting the numbers of prevented injuries is problematic, however, since this benefit depends on trends in aircraft size and usage. Using estimates from *FAA Aviation Forecast*, this analysis assumes that the average air carrier airplane has 161 seats and a load factor of 66%. The historical data show that approximately 7.7% of passengers and crew involved in a bird strike accident are killed; an additional 4.7% are injured (see Table 4).

Table 4. **Historical Distribution of Injuries For Bird Ingestion Accidents**

Fatalities/Injuries	
Total passengers/crew	452
Fatalities	35
Injuries	21
Prob(Fatality,Injury | accident)	
Fatalities	0.0774
Injuries	0.0465

The projected number of fatalities per bird ingestion-related airplane crash, then, is equal to the number of seats times the load factor times the historical percentage of people killed in such accidents (161 x 66% x 7.7% ≅

[6] E. C. Cleary, S. E. Wright, and R. A. Dolbeer. "Wildlife Strikes to Civil Aircraft in the United States 1990-1999" - forthcoming.

8). Similarly, the expected number of injuries given a bird ingestion-related accident is (161 x 66% x 4.7% ≅ 5). Table 5 computes the annual expected per airplane benefit associated with a reduction in the risk of fatalities or injuries for a representative passenger airplane.

Table 5. **Benefits of Averted Fatalities and Injuries**
(For a representative transport category airplane)

(1) Est. risk reduction per million departures	0.0186
(2) Air Carrier departures/year/AC (mil.)	0.0015
(3) Average seats per airplane	161
(4) Average load factor	66%
(5) Crew for notional airplane	6
(6) Total Occupants	112
(7) Prob(killed | accident)	0.0774
(8) Prob(injured | accident)	0.0465
(9) Value of a fatality averted	$2.7m
(10) Value of an injury averted	$518K
(11) Expected annual benefit from averted fatalities	$654
(12) Expected annual benefit from averted injuries	$75

Lines (1) and (2): See Table 3.
Lines (3) and (4): Average seating capacity and load factor for Form 41 air carriers in 1996. See: FAA, *FAA Aviation Forecasts, Fiscal Years 1996-2007*, Table 6.--Baseline Air Carrier Forecast Assumptions, p. IX-8. Also, see footnote 5.
Line (6): Line (5) plus product of lines (3) and (4).
Lines (7) and (8): See Table 4.
Lines (9) and (10): Official DOT values.
Line (11): Product of lines (1), (2), (6), (7), and (9).
Line (12): Product of lines (1), (2), (6), (8), and (10).

2. Benefits of avoided property loss

The annual per airplane benefit of avoided property loss can similarly be computed as:

$$B_p = (D \times (P_c - P_n)) \times V$$

Assuming that the replacement value, V, of a typical commercial transport airplane is $23.5 million; the annual per airplane benefit from avoided aircraft loss is approximately $657.[7]

3. Benefits of reduced maintenance costs

According to an industry expert, the rule will also have the effect of reducing repair costs by 90%, by raising the damage threshold (the bird weight which produces engine damage) by one pound, from 0.5 pounds to 1.5 pounds.[8] Estimating these savings, however, is difficult since bird ingestion damage is probabilistic. That is, the ingestion of a bird of a given weight will cause damage of a given severity only with some probability (with smaller birds less likely to cause damage than larger birds). Moreover, it is not clear that all types of damage will be uniformly affected by the new standards. One could argue, then, that mechanically applying the 90% rule to all repair costs overstates the potential savings. Ideally, estimating this benefit would involve the evaluation of test and in-service data comparing engine designs certificated under the previous and new regulations. In the absence of these data, FAA makes some simplifying and conservative assumptions (based on historical bird ingestion information) to derive an estimate of the savings arising from reduced repair costs.

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[7] The benefit-cost analysis is based on a notional twin engine jet airplane. FAA estimates its price at $47 million in 1996 dollars. (Based on a survey of new airplane prices compiled by an insurance consultancy. See: Airclaims Limited, *International Aircraft Price Guide*, Winter, 1996.) Replacement cost is assumed to be one-half the new airplane value. See: FAA, *Economic Values of Evaluation of Federal Aviation Administration Investment and Regulatory Programs*, Report FAA-APO-90-10, October, 1989.

[8] This is a result of increasing the weight of the largest medium bird from 1.5 to approximately 2.5 pounds.

In this approach, the expected value of savings due to reduced bird ingestion damage is equal to the product of the reduction in the probability of damage given the ingestion of a bird of given weight, r(w), times the probability of ingesting a bird of that weight, P_i(w), times the cost of repair, C(w), summed over all bird weights:

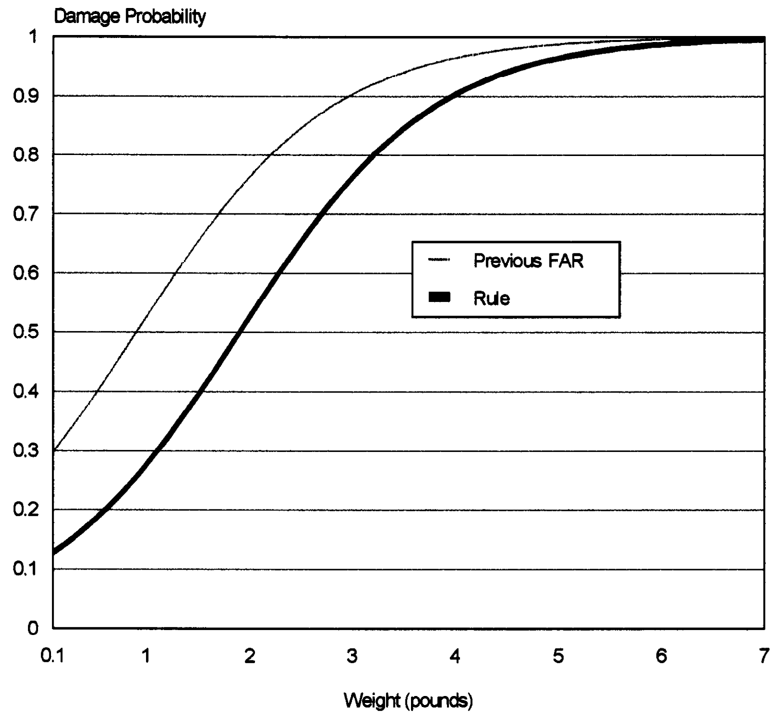
$$\sum_{w} r(w)\, p_i(w) C(w)$$

In order to estimate the reduction in the likelihood of engine damage, the FAA postulates that the probability, P_d(w), of damage given the ingestion of a bird of weight, w, can be described by a logit model with parameters μ and σ.[9]

$$P_d(w) = \frac{1}{1+\exp\left\{-\left(\frac{\pi}{\sqrt{3}}\right)\left(\frac{w-\mu}{\sigma}\right)\right\}}$$

Figure 1. **Probability of Damage by Bird Weight**

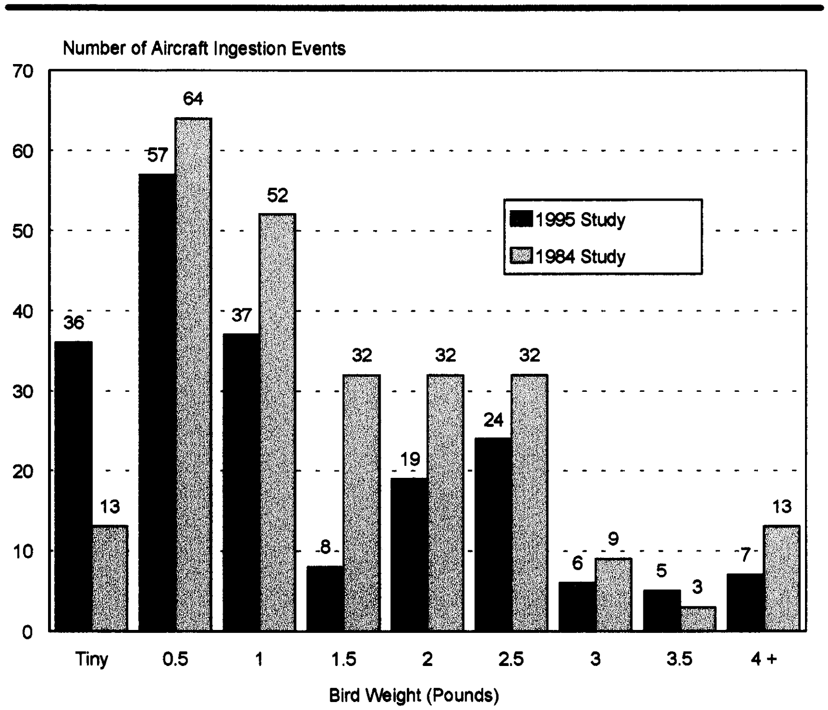
[9] Logit analysis is applied since the dependent variable is dichotomous; that is, damage either occurs or does not occur. A computer program estimates the model by computing parameters that maximize the likelihood of obtaining the observed sample.



Damage probability curves under previous Federal Aviation Regulations and under this rule are illustrated in Figure 1. The shift in $P_d(w)$ in Figure 1, then, is a measure of the rule's effect on the likelihood of engine damage as a result of increasing the damage threshold.[10]

Figure 2. **Frequency Distribution of Bird Ingestion Events By Weight-Class**

[10] The equation was estimated using bird ingestion and engine damage data for the period January 1989-August 1991. The data were collected by engine manufacturers and compiled by the FAA Technical Center (see Banilower, *op. cit.*). The estimated values of μ and σ are 0.9035 and 1.7033, respectively (where bird weight is measured in pounds). The effect of this rule is approximated by shifting μ by one pound.



The equations illustrated in Figure 1, in turn, are used to estimate the reduction in the risk of engine damage for discrete weight-classes of birds.[11] The distribution of bird ingestion events, by weight class, is computed directly from the Technical Center 1995 study sample (see Figure 2).[12] Average repair costs, assumed to be an increasing function of bird weight, are estimated using repair cost data collected by the Air Transport Association and Technical Center bird ingestion damage information (See Appendix II). Assuming an annual average of 1,500 departures, the expected savings from reduced repair costs per aircraft per year are $4,654. The calculations are shown in Table 6.

Table 6. **Calculation of the Rule's Effect on Repair Costs**

11 Following the convention used in FAA Technical Center studies of bird ingestion, these categories are "Tiny", 0.5 lb, 1.0 lb., 1.5 lb., 2 lb., etc.

12 Banilower, *op. cit.* An analysis of the 1984 sample appears in Frings, Gary, *A Study of Bird Ingestions Into Large High Bypass Ratio Turbine Aircraft Engines*, U.S. Department of Transportation, Federal Aviation Administration, DOT/FAA/CT-84/13. In this regulatory evaluation, the weight distribution of all bird ingestion events is assumed to equal the distribution of those events for which bird weight could be determined.

Bird class (1)	Ingest Rate (2)	$P_d(w)$ Before (3)	$P_d(w)$ After (4)	Before -after (5)	Rate reduct. (6)	Avg repair cost	Saving/ mil ops (7)	Saving/A C/year (8)
Tiny	38.57	0.3691	0.1678	0.2013	7.76	$67,378	$522,992	$784
0.5	61.33	0.3942	0.1832	0.2110	12.94	$66,989	$866,739	$1,300
1.0	39.84	0.5257	0.2765	0.2492	9.93	$99,531	$660,573	$991
1.5	8.53	0.6537	0.3942	0.2595	2.21	$68,408	$151,406	$227
2.0	20.55	0.7627	0.5257	0.2371	4.87	$72,254	$351,983	$528
2.5	25.92	0.8456	0.6538	0.1919	4.97	$77,492	$385,408	$578
3.0	6.32	0.9031	0.7627	0.1404	0.88	$83,423	$74,031	$111
3.5	5.37	0.9408	0.8456	0.0952	0.51	$89,372	$45,693	$69
4.0+	7.59	0.9643	0.9031	0.0612	0.46	$94,823	$44,051	$66
Totals								$4,654

(1) Bird size class (see Banilower, *op. cit.*, p 30, Table 4.6).
(2) Estimated ingestion rate by size using Banilower data (per million aircraft operations).
(3) Probability of damage by weight under current FAR (from Banilower data).
(4) Probability of damage computed by shifting damage threshold.
(5) Measure of risk reduction [column (3) minus column (4)] (per million aircraft operations).
(6) Reduction in the number of repairs per million aircraft operations [column (2) times column (5)].
(7) Estimated per aircraft savings per million aircraft operations.
(8) Estimated annual saving per aircraft. Assumes 1,481 departures per year. *FAA Statistical Handbook of Aviation, Calendar Year 1992.*

4. Unquantified benefits

Another benefit, while difficult to quantify, has important market impacts. Current regulations impose a substantial regulatory burden on manufacturers of small turbine engines. For example, the medium bird test for an engine with an inlet area of 301 square inches requires twice the bird mass (two 1.5 pound birds) as the medium bird test for an engine with a 299 square inch inlet area (one 1.5 pound bird). This, in turn, places restrictions on the size of aircraft powered by small turbine engines. One manufacturer of small jet aircraft reported that one of its aircraft designs explicitly takes into consideration the size of the inlet and, in particular, the 300 square inch threshold.

In view of the bird ingestion history of small turbine engines, the rule relaxes the medium bird weight requirements. Theoretically, this will reduce the disincentives that have made some engines - and, therefore, some aircraft - uneconomical to produce. As a result, consumers are expected to benefit from a wider offering of products with better performance.

C. Comparison of benefits and costs

In order to compare the lifecycle costs and benefits of the rule, the evaluation considers a hypothetical representative engine certification. As noted earlier, the engines are assumed to be installed on a notional twin-engine jet transport with a seating capacity of 161. In addition, this calculation assumes the following: 1) incremental engine certification testing costs are incurred in years 0 and 1 (these are the costs associated with two additional component tests), 2) production of the engines commences in year 2, 3) engines are installed in aircraft and enter service in year 3, 4) there are two engines per aircraft, 5) each engine has a 15-year service life, 6) 24 engines are produced per year for ten years, so that there are 240 total engines and 120 airplanes per certification, and 7) the discount rate is 7%,. The results are shown in Table 7. Under these conditions, the estimated discounted benefits of the rule, at $4.333 million, exceed the discounted costs $3.906 million. These estimates remain valid; public comments were not received on the preliminary economic evaluation. Also, since the NPRM, there have been several new incidents involving bird ingestion. Consequently, the FAA believes that the benefits of the rule justify its costs.

Table 7. **A Comparison of Incremental Benefits and Costs For a Representative, Hypothetical Engine Certification (thousands of dollars)**

				Incremental Costs				Incremental Benefits				
T	Disc Rate	Eng Prod	AC in Srv	Cert Cost	Op Cost	Tot. Cost	Disc Cost	Maint. Ben	Prop Ben	Inj Ben	Tot Ben	Disc Ben
0	1.00	0	0	250	0	250	250	0	0	0	0	0
1	0.93	0	0	250	0	250	234	0	0	0	0	0
2	0.87	24	0		0	0	0	0	0	0	0	0
3	0.82	24	12		57	57	47	56	8	17	72	59
4	0.76	24	24		114	114	87	112	16	26	145	111
5	0.71	24	36		172	172	122	168	24	35	217	155
6	0.67	24	48		229	229	153	223	32	44	290	193
7	0.62	24	60		286	286	178	279	39	52	362	226
8	0.58	24	72		343	343	200	335	47	61	435	253
9	0.54	24	84		401	401	218	391	55	70	507	276
10	0.51	24	96		458	458	233	447	63	79	580	295
11	0.48	24	108		515	515	245	503	71	87	652	310
12	0.44		120		572	572	254	558	79	87	725	322
13	0.42		120		572	572	238	558	79	87	725	301
14	0.39		120		572	572	222	558	79	87	725	281
15	0.36		120		572	572	207	558	79	87	725	263
16	0.34		120		572	572	194	558	79	87	725	246
17	0.32		120		572	572	181	558	79	87	725	229
18	0.30		108		515	515	152	503	71	79	652	193
19	0.28		96		458	458	127	447	63	70	580	160
20	0.26		84		401	401	104	391	55	61	507	131
21	0.24		72		343	343	83	335	47	52	435	105
22	0.22		60		286	286	65	279	39	44	362	82
23	0.21		48		229	229	48	223	32	35	290	61
24	0.20		36		172	172	34	168	24	26	217	43
25	0.18		24		114	114	21	112	16	17	145	27
26	0.17		12		57	57	10	56	8	9	72	12
Tot				500	8,586	9,086	3,906	8,377	1,183	1,312	10,872	4,333

IV. Regulatory Flexibility Analysis

The Regulatory Flexibility Act of 1980 establishes "as a principle of regulatory issuance that agencies shall endeavor, consistent with the objectives of the rule and of applicable statutes, to fit regulatory and informational requirements to the scale of the businesses, organizations, and governmental jurisdictions subject to regulation." To achieve that principle, the Act requires agencies to solicit and consider flexible regulatory proposals and to explain the rationale for their actions. The Act covers a wide range of small entities, including small businesses, not-for-profit organizations and small governmental jurisdictions.

Agencies must perform an assessment of all rules to determine whether the rule will have a significant economic impact on a substantial number of small entities. If the determination is that it will have such an impact, the agency must prepare a regulatory flexibility analysis as described in the Act.
However, if after a preliminary analysis for a proposed or final rule, an agency determines that a rule is not expected to have a significant economic impact on a substantial number of small entities, Section 605(b) of the 1980 Act provides that the head of the agency may so certify. The certification must include a statement providing the factual basis for this determination, and the reasoning should be clear.

The FAA has conducted the required assessment of this rule and determined that it will not have a significant economic impact on a substantial number of small entities. The following text summarizes the basis for this determination.

The rule will apply only to newly-designed turbine aircraft engines certificated in the future. Each new engine certification can affect two types of small entities: manufacturers of turbine engines and operators of aircraft.

Manufacturers will be required to perform additional analysis or testing to demonstrate that the new bird ingestion requirements are met. There are nine turbine aircraft engine manufacturers in the U.S. (this count includes subsidiaries of foreign entities, and consortiums of domestic and/or foreign entities).[13] Information available to the FAA indicates that only one of these - a U.S. manufacturer of small turbine engines - has less than 1,500 employees and therefore qualifies as a small business under SBA employment criteria. If all certification costs are assumed to be borne by the manufacturers, the FAA would conclude that with only one manufacturing firm being classified as "small", there will not be an impact on small business.

In addition, the FAA analyzed the small business impact with a tougher criterion. The FAA assumes that all manufacturing costs will be borne by the customers of manufacturers who purchase new equipment. The rule is estimated to add about $250,000 for a small engine type produced by the single small entity: these are one-time certification costs. The FAA estimates that the rule will impose no incremental manufacturing costs.

Aircraft operators will incur slightly higher engine prices and will pay increased operating or fuel costs due to the small decrease in engine efficiency described in the full regulatory evaluation. According to FAA data, there are about 3,000 air carriers having less than 1,500 employees--approximately 100 part 121 (or dual 121/135 certificate) air carriers, and 2,900 part 135 air carriers.

Assuming conservatively that: 1) all incremental certification costs are passed on to the buyer/operator, 2) the manufacturer recovers incremental certification costs by applying a uniform price increase to 240 engines produced during a ten-year production run, and 3) that the discount rate is 7 percent; then the FAA estimates that average new engine prices will increase by approximately $3,070 per larger engine and $1,587 per smaller engine. When these costs are amortized over the 15-year life of a new engine (again, assuming a 7% discount rate), the incremental annualized cost per new engine is approximately $315 and $163 for larger and smaller engines, respectively. Therefore, assuming a typical airplane has two engines, the incremental

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13 *Aviation Week and Space Technology Aerospace Sourcebook*, January 8, 1996.

annualized cost for a large airplane is approximately $630 and the incremental annualized cost for a smaller airplane is approximately $326. These costs are only a small percentage of new engine overall costs, and a very small percentage of carrier revenues.

For larger new engines, the rule will also increase annual airplane operating costs as a result of the new medium bird ingestion requirements (these requirements will have a negligible effect on smaller engines). On average, annual operating costs per large airplane are estimated to increase by approximately $4,770 (see Table 1). However, the reduction in average annualized maintenance costs, associated with the more damage-resistant engines that are expected to be developed as a result of this rule, are expected to nearly completely offset incremental operating costs.

Therefore, total annualized costs for operators who purchase new engines for larger and smaller airplanes will be approximately $630 and $326 per airplane, respectively. Consequently, the FAA certifies that the rule will not have a significant economic impact on a substantial number of small entities.

V. International Trade Impact Analysis

The Trade Agreement Act of 1979 prohibits Federal agencies from engaging in any standards or related activities that create unnecessary obstacles to the foreign commerce of the United States. Legitimate domestic objectives, such as safety, are not considered unnecessary obstacles. The statute also requires consideration of international standards and where appropriate, that they be the basis for U.S. standards. In addition, consistent with the Administration's belief in the general superiority and desirability of free trade, it is the policy of the Administration to remove or diminish to the extent feasible, barriers to international trade, including both barriers affecting the export of American goods and services to foreign countries and barriers affecting the import of foreign goods and services into the United States.

Turbine engines are manufactured by U.S. and foreign companies. In accordance with the above statute and policy, the FAA has assessed the potential effect of this rule and has determined that it will impose the same costs on domestic and international entities, and will thus have a neutral impact on international trade.

VI. Unfunded Mandates Reform Act Analysis

Title II of the Unfunded Mandates Reform Act of 1995 (the Act), codified in 2 U.S.C. 1501-1571, requires each Federal agency, to the extent permitted by law, to prepare a written assessment of the effects of any Federal mandate, in a proposed or final agency rule, that may result in an expenditure by State, local, and tribal governments, in the aggregate, or by the private sector, of $100 million or more (adjusted annually for inflation) in any 1 year. Section 204(a) of the Act, 2 U.S.C. 1534(a), requires the Federal agency to develop an effective process to permit timely input by elected officers (or their designees) of State, local, and tribal governments on a proposed "significant intergovernmental mandate." A "significant intergovernmental mandate" under the Act is any provision in a Federal agency regulation that would impose an enforceable duty upon State, local, and tribal governments, in the aggregate, of $100 million (adjusted annually for inflation) in any 1 year. Section 203 of the Act, 2 U.S.C. 1533, which supplements section 204(a), provides that before establishing any regulatory requirements that might significantly or uniquely affect small governments, the agency shall have developed a plan that, among other things, provides for notice to potentially affected small governments, if any, and for a meaningful and timely opportunity to provide input in the development of regulatory proposals.

This rule does not contain a Federal intergovernmental or private sector mandate that exceeds $100 million in any one year.

Appendix I: Bird ingestion events involving large jet transports

Events includes: 1) accidents, 2) events involving multiple engine power loss of 25% or greater, 3) military variants of commercial jet transports (although these cases are *not* used in the accident/benefit analysis). Airplane and location detail are omitted in the case of proprietary data.

Year	Location	Airplane	Description
1975			Bird ingestion led to aborted take-off. No fatalities or injuries.
1975	US	DC10-30	During take-off roll, struck seagulls. Rejected takeoff. Uncontained engine failure. Aircraft destroyed by fire. 128 passengers, 3 crew. No fatalities or injuries.
1977			Bird ingestion led to aborted take-off. No fatalities or injuries.
1978	Belgium	B737-200	Aircraft overran runway during rejected takeoff following bird ingestion. Aircraft destroyed by fire. 3 crew. No fatalities or injuries
1979			Air turnback following bird ingestion. No fatalities or injuries.
1982			Bird ingestion on approach. No fatalities or injuries.
1983			Aborted take-off following bird ingestion. No fatalities or injuries.
1986	India	A300B	Rejected takeoff following bird ingestion. Aircraft declared a hull loss. 185 passengers, 17 crew. No fatalities or injuries.
1987			Aborted take-off following bird ingestion. No fatalities or injuries.
1987			**Military**. Air turnback following bird ingestion. No fatalities or injuries.
1988	Ethiopia	B737-200	Crash during air turnback following bird ingestion into both engines. Aircraft destroyed. 105 passengers/crew. 35 fatalities, 21 injuries.
1989			Aborted take-off following bird ingestion. No fatalities or injuries.
1990	Ethiopia	B707-300	Rejected take-off following bird ingestion. Aircraft destroyed by fire. 4 crew. No fatalities, 1 serious injury.
1995	US	E-3 AWACS	**Military**. Aircraft crashed shortly after take-off following multiple engine bird ingestion. Aircraft destroyed. 24 aboard, all killed.
1996	Greece	E-3 AWACS	**Military**. Rejected take-off following bird ingestion. Aircraft not repaired. No fatalities or injuries.
	Summary		**Commercial Hull Losses** Number of Hull Losses: 5 Passengers/crew: 452 Number of fatalities: 35 Number of injuries: 21

Appendix II: Estimation of repair costs as a function of bird weight

About one-half of bird ingestion events result in damage to the engine, with the probability of damage increasing as bird weight increases. Generally, the severity of damage also increases with bird weight. For example, the 1995 FAA Technical Center study (see footnote 1) observes that for events involving birds weighing 1 pound or less, less than half of the cases of damage were classified as "severe." On the other hand, for events involving birds weighing more than 1 pound, 68% of the cases of damage were classified as "severe."[14]

The available data did not permit a direct estimate of the relationship between repair costs and bird weight (for example, by using ordinary least squares). Instead, a repair cost "function" was estimated as follows:

1) Costs for different types of repairs were computed as averages of estimates reported by operators (these data were compiled by the Air Transport Association). Average costs are summarized in Table AII.1.

Table AII.1. **Average Repair Costs for Engine Damage Due to Bird Ingestion**[15]

Damage	Average Cost
Nicked Fan Blade	$ 100
Bent/Broken Fan Blade	$ 4,000
Core Damage	$150,000
Nose Cowl	$195,000
Nacelle	$200,000

14 The Technical Center database classifies damage as "minor" or "severe." Examples of minor damage include fan blade leading edge distortion, 1 to 3 bent or dented fan blades, or acoustic panel damage. Examples of severe damage include core or turbine damage.

15 These costs include labor and material costs, but do not include the revenue lost from removing an airplane from service.

2) These values were applied to descriptions of engine damage contained in the Technical Center database. This yields an average repair cost for "severe" damage events of approximately $114,000. Similarly, the average repair cost for "minor" damage events is $12,000.

3) The relationship between the probability of a "severe" event and bird weight was estimated via a logit model. Such models are used to estimate the relationship between the probability of an event and an explanatory variable. In this case, the results were used to estimate the share of severe events relative to the total number of bird ingestion events.

4) Repair costs for any weight-class, then, are the sum of "severe damage" and "minor damage" repair costs weighted by the relative share of severe and minor events. These calculations are summarized in Table AII.2 below.

Table AII.2. **Calculation of Average Repair Costs, by Bird Weight**

Weight	Damage Probability		"Severe" Share	Cost Function
Tiny	0.3691	0.2004	0.5429	$67,378
0.5	0.3942	0.2125	0.5391	$66,989
1.0	0.5257	0.2810	0.5346	$99,531
1.5	0.6537	0.3615	0.5530	$68,408
2.0	0.7627	0.4506	0.5907	$72,254
2.5	0.8456	0.5429	0.6421	$77,492
3.0	0.9031	0.6324	0.7002	$83,423
3.5	0.9408	0.7136	0.7586	$89,372
4.0+	0.9643	0.7830	0.8120	$94,823